Changes of Electrocochleographic Responses During Cochlear Implantation Presented at the Annual Meeting of ADANO 2016 in Berlin

Dalbert, Adrian ; Pfiffner, Flurin ; Hoesli, Marco ; Meerwein, Christian ; Veraguth, Dorothe ; Roosli, Christof ; Huber, Alexander

Abstract: OBJECTIVE: To assess by electrocochleography (ECoG) at which times during cochlear implantation changes of cochlear function occur. METHODS: Tone bursts with a frequency of 500 or 750 Hz were used as acoustic stimuli. The recording electrode was placed on the promontory and left in an unchanged position for all ECoG recordings. RESULTS: Eight subjects were included. After opening the cochlea, an increase of the amplitude of the ECoG signal was detectable in four subjects (mean change 3.9 dB, range from 0.2 to 10.8 dB). No decreases were detectable after opening the cochlea or during the first half of the insertion of the CI electrode array (mean change 0.5 dB, range from -2.2 to 1.6 dB). During the second half of the insertion, the amplitude of the ECoG signal decreased in four subjects (mean change -2.5 dB, range from -0.04 to -4.8 dB). If a decrease occurred during the second half of the insertion, then the decrease continued in the earliest phase after insertion of the CI electrode array (mean change -2.1 dB, range from -0.5 to -5.8 dB). CONCLUSION: Pressure changes inside the cochlea can lead to an increase of ECoG signals after opening the cochlea. If detectable, then a decrease of ECoG signals occurs during the second half of the insertion of the CI electrode array and continues in the earliest phase after completed insertion. These findings suggest that cochlear trauma occurs toward the end of the insertion and that trauma-dependent postoperative mechanisms contribute to postoperative hearing loss.

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*†Adrian Dalbert, *†Flurin Pfiffner, *†Marco Hoesli, *†Christian Meerwein, *†Dorothe Veraguth, *Christof Roosli, and *†Alexander Huber

*University of Zurich; and †Department of Otorhinolaryngology—Head and Neck Surgery, University Hospital Zurich, Zurich, Switzerland

Objective: To assess by electrocochleography (ECoG) at which times during cochlear implantation changes of cochlear function occur.

Methods: Tone bursts with a frequency of 500 or 750 Hz were used as acoustic stimuli. The recording electrode was placed on the promontory and left in an unchanged position for all ECoG recordings.

Results: Eight subjects were included. After opening the cochlea, an increase of the amplitude of the ECoG signal was detectable in four subjects (mean change 3.9 dB, range from 0.2 to 10.8 dB). No decreases were detectable after opening the cochlea or during the first half of the insertion of the CI electrode array (mean change 0.5 dB, range from −2.2 to 1.6 dB). During the second half of the insertion, the amplitude of the ECoG signal decreased in four subjects (mean change −2.5 dB, range from −0.04 to −4.8 dB). If a decrease occurred during the second half of the insertion, then the decrease continued in the earliest phase after insertion of the CI electrode array (mean change −2.1 dB, range from −0.5 to −5.8 dB).

Conclusion: Pressure changes inside the cochlea can lead to an increase of ECoG signals after opening the cochlea. If detectable, then a decrease of ECoG signals occurs during the second half of the insertion of the CI electrode array and continues in the earliest phase after completed insertion. These findings suggest that cochlear trauma occurs toward the end of the insertion and that trauma-dependent postoperative mechanisms contribute to postoperative hearing loss.

Key Words: Cochlear implant—Cochlear implantation—Cochlear trauma—ECoG—Electrocochleography—Hearing preservation.

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Minimizing cochlear trauma during cochlear implantation has become a goal in all cochlear implant (CI) surgeries for multiple reasons (1): 1) It allows preservation of residual hearing and thereby electric-acoustic stimulation in selected patients (2); 2) it leads to less intracochlear fibrosis and ossification (3); 3) it enables access to possible future treatment options that are dependent on intact cochlear structures; 4) it leads to better speech perception in conventional CI recipients (1,4). Therefore, monitoring cochlear trauma during cochlear implantation has gained attention. Electrocochleography (ECoG) is a promising method for this purpose because animal studies have shown that histologically detectable cochlear trauma during insertion of an electrode into the cochlea results in an immediate decrease of ECoG signals (5–10).

In human CI recipients, ECoG recordings have been attempted from extra- and intracochlear sites (11–18). In patients with some degree of residual hearing before surgery, ECoG signals have been detected in > 90% of cases (12,19). Moreover, a correlation between loss of residual hearing 4 weeks after surgery and a decrease of ECoG signals immediately after insertion of the CI electrode array has been demonstrated (12,13,20). However, it remains unclear at which times during the insertion of the CI electrode array such decreases of ECoG signals occur. Furthermore, extracochlear ECoG recordings before and after insertion of the CI electrode array have revealed increases of the amplitude of ECoG signals in some cases (11–13). The time of occurrence of such increases is unknown.

Postoperative intracochlear ECoG recordings have further suggested that deterioration of cochlear function mainly occurs during the first days after surgery (14). However, it is currently unknown if deterioration starts

Address correspondence and reprint requests to Adrian Dalbert, M.D., Department of Otorhinolaryngology—Head and Neck Surgery, University Hospital Zurich, Frauenklinikstrasse 24, CH-8091 Zurich, Switzerland; E-mail: adrian.dalbert@usz.ch

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during surgery or in the first few minutes afterward and continues in the early postoperative phase or if the loss of cochlear function sets in later.

The optimal recording parameters needed to monitor cochlear trauma by ECoG during the insertion of an electrode into the cochlea have not been established definitely. Findings in animal studies suggest that the cochlear microphonic (CM), a hair cell potential, as part of the ongoing ECoG signal is the most sensitive potential to detect cochlear trauma (10). However, in the case of low-frequency acoustic stimuli at high intensities—as needed in human CI recipients—a separation between the CM and the auditory nerve neurophonic —a neural potential—is difficult (21) and has not yet been done. Consequently, the amplitude of the ongoing ECoG signal, which is the combination of the CM and auditory nerve neurophonic should be analyzed (11–14,18).

This study aimed to: 1) assess at which times during cochlear implantation decreases or increases of the ongoing ECoG signals occur and 2) monitor cochlear function using the ongoing ECoG signal in the first few minutes after complete insertion of the CI electrode array.

METHODS

The study was conducted after approval of the Ethical Committee of Zurich (KEK-ZH-Nr. 2013-0317) and in concordance with the Helsinki Declaration. The indication for cochlear implantation was given after presurgical evaluations at the CI Center of the University Hospital of Zurich, Switzerland. Subjects had to be > 18 years old and provided written informed consent before surgery.

Surgery and ECoG Recordings

All surgeries were performed at the University Hospital of Zurich by A.H. or C.R. A single dose of ceftriaxone 2 g and methylprednisolone 250 mg was provided intravenously at induction of the anesthesia. Before surgery, an insert earphone (Biologic Systems, Mundelein, IL) and a microphone (ER-7C, Etymotic, Inc., Elk Grove Village, IL) were positioned in the ear canal and two needle electrodes (20 × 0.3 mm, Neurosign, Magstim Co., Wales, U.K.) were placed on the forehead (''ground'') and in the contralateral preauricular region (''negative'').

Next, a standard anterior mastoidectomy and posterior tympanotomy were performed. A detailed description of the surgical procedure can be found a previous publication (12). After visualization of the round window, a third needle electrode (Neurosign) was positioned on the promontory (''positive''). This electrode was fixed in the mastoidectomy cavity by bone wax and left in an unchanged position for all ECoG recordings.

Once impedances were < 10 kOhm on all needle electrodes, baseline ECoG recordings were conducted. Afterward, an anterior-inferior cochleostomy or an incision of the round window membrane was performed, followed by the second ECoG recording. The CI electrode array was then inserted in a stepwise manner. During insertion, serial ECoG recordings were performed while the insertion was paused and the array held in an unchanged position until the recording was completed. After the insertion was fully completed and the insertion site sealed with soft tissue, the ECoG recording was repeated. From this point on, there was no further manipulation of the CI electrode array. Intraoperative CI telemetry was performed to confirm function of the CI and after completion, then the last ECoG recording followed. The needle electrode was removed and the wound closed in layers.

The Navigator Pro stimulation/recording device and the AEP software from Biologic Systems (Mundelein, IL) were used for acoustic stimulation and recording. For baseline ECoG recordings, tone bursts at 250, 500, 750, and 1000 Hz were used as acoustic stimuli. The sound pressure was 85 dB nHL at 250 Hz, 95 dB nHL at 500 Hz, and 100 dB nHL at 750 and 1000 Hz. All further recordings were conducted at the frequency with the most robust ECoG response in the baseline recordings.

Responses to 400 tone bursts with alternating starting phases were filtered and averaged. The high pass filter was set at 10 Hz, the low pass filter at 3000 Hz for acoustic stimuli at 250, 500, and 750 Hz, and at 5000 Hz for acoustic stimuli at 1000 Hz. The tone burst rise and fall times were two cycles shaped by a Blackman window. The plateau phase was four cycles at 250 Hz, 10 cycles at 500 Hz, 14 cycles at 750 Hz, and 20 cycles at 1000 Hz. The recording window was 32 milliseconds.

The data were exported from the AEP software using the AEP to ASCIII program from Biologic Systems. Postprocessing was done with MATLAB (MathWorks Inc., Natick, MA) and GraphPad Prism V5.04 (GraphPad Software Inc., La Jolla, CA).

The data from condensation and rarefaction phases were stored separately. The average curve was determined by subtracting both responses and the sum curve by adding both responses. The spectrum of each ECoG response was obtained for the analysis of the amplitude of the ongoing ECoG signal. A time window (9–23 ms), isolating the ongoing ECoG signal from the CAP, was defined and a fast Fourier transform conducted.

The amplitude of the ongoing ECoG response was defined as the sum of the response amplitude at the frequency of the acoustic stimuli (first harmonic) and at the frequency of twice the acoustic stimuli (second harmonic).

RESULTS

Eight subjects with a mean age of 47 years (range from 20–71 yrs) were included. Five subjects received a Cochlear Nucleus CI422/CI522 device and three subjects a Cochlear Nucleus CI24RE(CA). The subject demographics are summarized in Table 1.

There were no complications during surgery or postoperatively. Gusher after cochleostomy or incision of the round window membrane did not occur. Full insertion without detectable resistance for the surgeon could be achieved and postoperative radiographic studies (cochlear view X-ray or cone beam computed tomography) showed no tip fold-over or kinking in all subjects. In all subjects in which a cone beam computed tomography was conducted (S1–S4, S7), a correct position of the electrode array in the scala tympani was assumed.

Electrophysiological Findings

The most robust ECoG responses were detectable in response to a 500-Hz tone burst in subjects S1, S3, S4, S5, S6, and S7 and at 750 Hz for S2 and S8, and these frequencies were used as the acoustic stimuli.

Figure 1 displays two examples of the time waveforms of ECoG responses at different measurement points

TABLE 1. *Subject demographics*

Subject No.	Age (Yr)	Sex	Cochlear Implant	Surgical Approach	Preoperative PTA (dB HL)
S1	62	M	Nucleus CI-422	Round window	79
S2	61	M	CI24RE(CA)	Cochleostomy	94
S3	44	F	CI24RE(CA)	Cochleostomy	104
S4	71	F	Nucleus CI-522	Round window	86
S5	61	F	Nucleus CI-522	Round window	64
S6	30	F	Nucleus CI-522	Round window	78
S7	20	F	CI24RE(CA)	Cochleostomy	94
S8	28	M	Nucleus CI-522	Round window	104

PTA was calculated from the hearing thresholds at 250, 500, 1000, 2000, and 4000 Hz.
PTA indicates pure-tone average.

during cochlear implantation in two different subjects (S2 and S5). In S2, an increase of the ECoG response after cochleostomy was visible. Until the halfway point of insertion, no detectable decrease of the ECoG response occurred. Afterward, the amplitude of the ECoG response continuously decreased until the last ECoG recording after CI telemetry. Such a pattern could be registered in S1, S2, S4, and S7.

In S5, no decrease of the ECoG response occurred until the last recording. Such a pattern was detectable in S3, S5, S6, and S8.

Increases of the amplitude of the ongoing ECoG signal were only detectable after opening the cochlea and occurred in S1, S2, S4, and S8. Such increases of the ongoing ECoG signal were visible after cochleostomy (S2) as well as after incision of the round window membrane (S1, S4, S8).

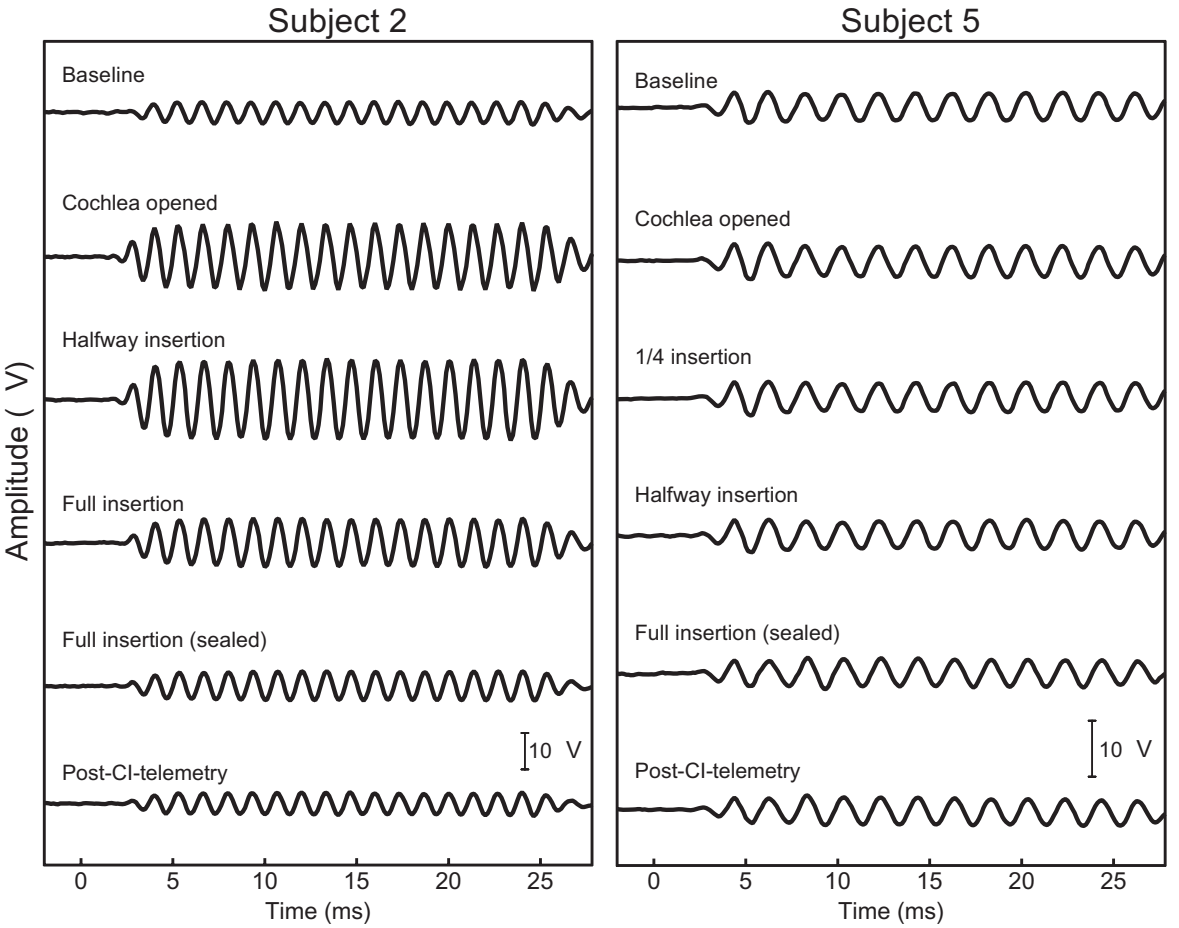

FIG. 1. Two examples of ECoG responses (*sum curves*) at different times during cochlear implantation. In the *left* row (S2), the ECoG signals increased after cochleostomy. Then, until halfway insertion, no change of the ECoG signal was detectable. Afterward, the amplitude of the ECoG signal continuously decreased until the last ECoG recording after CI telemetry. In the *right* row (S5), the ECoG signal remained unchanged until the last recording. ECoG indicates electrocochleography.

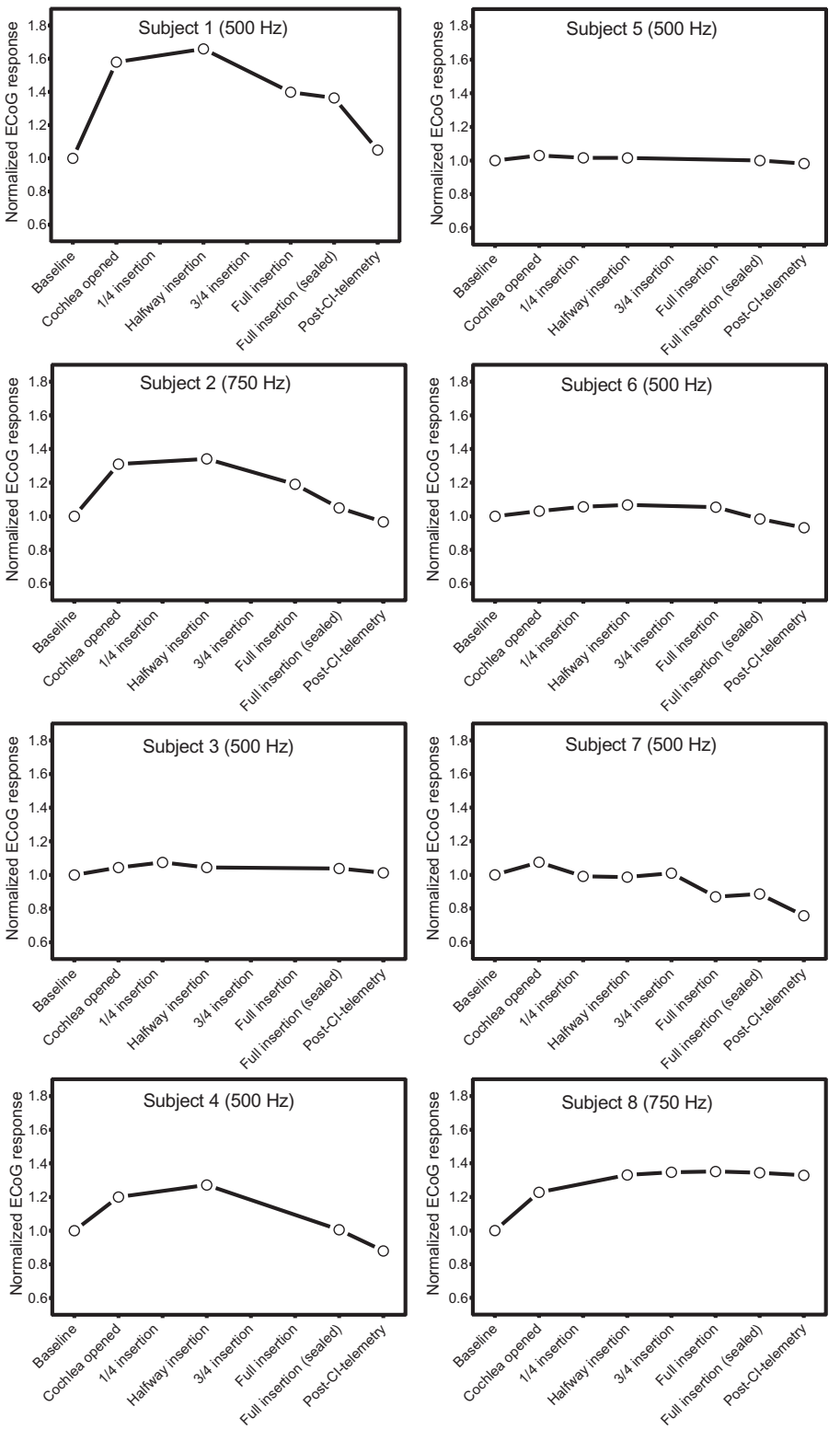

FIG. 2. The change of the amplitude of the ongoing ECoG signal over time for each subject. The amplitude is normalized to the amplitude of the ongoing ECoG signal in the baseline recording before opening the cochlea.

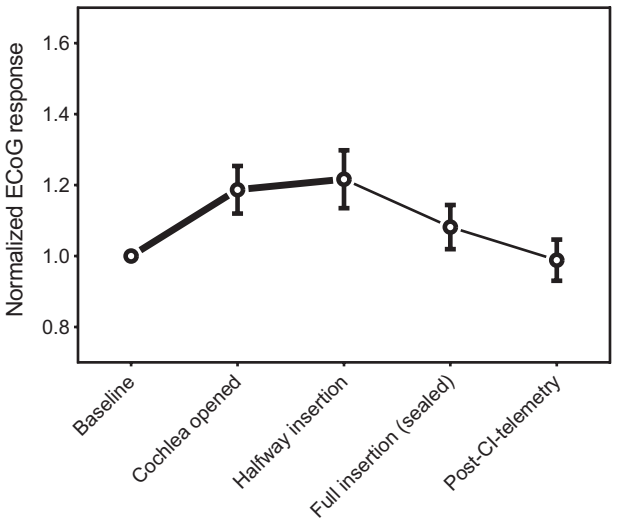

FIG. 3. Mean change of the ongoing ECoG signal over time. *Error bars* are standard deviation of the mean.

Decreases of the ECoG signal after opening the cochlea or during the first half of the insertion of the CI electrode array did not occur. In all subjects in which a decrease of the ongoing ECoG signal was detectable during the second half of the insertion (S1, S2, S4, S7), the decrease further continued in the first few minutes after complete insertion and sealing of the insertion site. Figure 2 illustrates the changes of the amplitude of the ongoing ECoG signal over time for each subject.

On average, an increase of the amplitude of the ongoing ECoG signal of 3.9 dB occurred after opening the cochlea (range from 0.2 to 10.8 dB). During the first half of the insertion, the mean change of the ongoing ECoG signal was 0.5 dB (range from −2.2 to 1.6 dB). The mean decrease during the second half of the insertion was −2.5 dB (range from −0.04 to −4.8 dB) and it continued until the last ECoG recording after CI telemetry (mean decrease from full insertion and sealed insertion site until the last ECoG recording −2.1 dB, range from −0.5 to −5.8 dB). The average change of the ongoing ECoG signal during surgery is displayed in Figure 3.

In five subjects (S1, S2, S6, S7, S8), ECoG recordings were performed before and after sealing the insertion site with soft tissue. In subjects S1, S2, and S6, a small reduction of the ongoing ECoG signal was recordable after sealing the insertion site; in the subjects S7 and S8 the signal remained unchanged (mean change −1 dB, range from −4.3 to 0.4 dB).

DISCUSSION

The primary aim of this study was to determine at which times during cochlear implantation changes of ECoG signals and therefore changes of cochlear function occur. Such insight may give further clues regarding the mechanisms causing loss of residual hearing and could guide future developments attempting to further reduce trauma during cochlear implantation and improve hearing preservation rates.

A decrease of ECoG signals occurred only during the second half of the insertion of the CI electrode array. Such a decrease was detectable in 50% of the subjects and in subjects receiving Cochlear Nucleus CI422/CI522 devices (S1, S4) as well as Cochlear Nucleus CI24RE(CA) devices (S2, S7). As cochlear trauma causes an immediate reduction of the ECoG signal (5–10), these findings suggest that cochlear trauma occurs toward the end of the insertion. This finding is in concordance with recently published findings from intracochlear ECoG recordings during cochlear implantation (20). However, because acoustic stimuli with a frequency of 500 or 750 Hz were used in all subjects, an alternative explanation is that cochlear trauma can be detected by low-frequency ECoG recordings only when the trauma reaches the tonotopic region of the acoustic stimulus. If this is true, then trauma may have occurred in an earlier stage of the insertion but was detected only when the CI electrode array reached the tonotopic regions of 500 or 750 Hz. Furthermore, besides trauma mechanical changes or pressure changes within the cochlea due to the insertion of the electrode array could also cause a change of the ECoG responses unrelated to damage to cochlear structures. A decrease of ECoG responses due to fluid accumulation in the middle ear can be excluded as the middle ear was accessible during all ECoG recordings and fluid was removed if present.

If a decrease of ECoG signals during insertion was detectable, then the decrease and therefore the deterioration of cochlear function continued in the earliest phase after complete insertion of the CI electrode array. This suggests that trauma-triggered postoperative mechanisms contribute to the postoperative hearing loss. In these subjects, the rapid time course supports mechanisms responsible for loss of cochlear function such as loss of the endocochlear potential or intracochlear bleeding (22) rather than inflammatory processes (23).

Opening the cochlea by cochleostomy or incision of the round window membrane leads to an increase of the ECoG signals in 50% of the subjects (S1, S2, S4, S8). Intracochlear pressure changes seem to be the most likely explanation for this finding (24). Contact with perilymph by the recording electrode placed on the promontory could be an alternative explanation. However, as the increase occurred before the insertion of the electrode array started and as there was no gusher in any subject, it seems unlikely that perilymph leaked at the time of the increase of the ECoG signal. Consequently, in future studies using extracochlear ECoG recordings, baseline recordings should be conducted after the cochlea has been opened.

No decrease of ECoG signals occurred after opening the cochlea. Therefore, it seems that if soft surgical principles are followed, then cochleostomy or incision of the round window membrane does not cause acute deterioration of cochlear function.

CONCLUSION

In extracochlear ECoG recordings, a decrease of ECoG signals during cochlear implantation occurs toward the end of the insertion of the CI electrode array. This suggests that cochlear trauma mainly occurs during the insertion of the electrode array in regions beyond the basal turn. If loss of cochlear function begins during insertion, then this process continues in the earliest phase after completed insertion, suggesting trauma-triggered postoperative mechanisms contributing to postoperative hearing loss. However, further studies are needed to correlate ECoG changes with cochlear trauma and elucidate the implications of such changes for hearing preservation and CI performance.

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